REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
11/29/95

3. REPORT TYPE AND DATES COVERED
Final 1/1/91 - 9/30/95

4. TITLE AND SUBTITLE
Signal Analysis, Synthesis and Processing Using Fractals and Wavelets

5. FUNDING NUMBERS
AFOSR-91-0034
2304/ES

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AFOSR-TR-96
0085

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research/PKA
Building 410
Bolling Air Force Base, DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

19960320 088

13. ABSTRACT *(Maximum 200 words)*

The research performed under this grant is summarized. In one component of the research, robust algorithms for signal processing with fractal signals were developed using wavelet-based representations. In a second component of the research, algorithms for addressing problems of detection, estimation and modeling using nonlinear and chaotic sgnals were developed. Finally, in a third component of the research, efficient algorithms for signal enhancement and active noise cancellation were developed. The resulting algorithms are promising candidates for a host of defense and related applications.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Final Report for AFOSR

Signal Analysis, Synthesis and Processing Using Fractals and Wavelets

January 1, 1991 - September 30, 1995

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Contract: AFOSR-91-0034-C
OSP Number: 62889

1 Summary of Results from Research

The research under this grant explored signal processing algorithms for a broad range of applications relevant to the needs of the Department of Defense in general, and the Air Force in particular. This work is extensively documented in numerous publications and several student theses, both Masters' and PhD. A comprehensive list of these publications and theses is provided in Section 2.

1.1 Signal Processing with Fractals and Wavelets

One component of the research explored and developed the use of self-similar and fractal random processes as models for a wide range of natural and man-made phenomena. Natural and extremely efficient representations for such processes were developed out of orthonormal wavelet theory. These representations, in turn, led to powerful algorithms for addressing fundamental problems of detection and estimation involving such processes.

Algorithms for generating rich classes of deterministic signals with self-similar and fractal characteristics were also developed for applications ranging from remote sensing to communications. For the communications applications specifically, we demonstrated how the use of fractal signals leads to a novel diversity strategy, which we referred to as "fractal modulation", that was well suited to certain classes of unreliable channels. Fractal modulation also represents a potentially promising for secure communication in a variety of scenarios.

Subsequent work in this area explored richer modeling frameworks based on generalized classes of fractal signals, and efficient modeling algorithms were developed. In addition, preliminary work was performed that explored efficient multiscale models for nonGaussian fractal processes. A principle focus within this component of the research was on fractal point processes, which are important models for a wide range of phenomena ranging from auditory neuron firings in the human ear to vehicular traffic and data network traffic. For these processes, we developed extremely efficient synthesis and analysis algorithms based on a multiscale Poisson process framework. In addition, these multiscale Poisson-based representations allowed a number of important detection and estimation problems that involve fractal point processes to be addressed.

1.2 Signal Processing with Nonlinear/Chaotic Signals and Systems

This research explored the use of signals arising out of the theory of nonlinear dynamics and chaos for a variety of signal processing applications. One aspect of this research involved the development of chaotic modeling algorithms for physical signals. These included some promising new classes of nonlinear autoregressive modeling techniques. A particular emphasis within this research was on robust algorithms. For example, techniques for detection, estimation, and modeling in the presence of both additive and convolutional distortion were explored in detail, and important new classes of recursive filtering and blind deconvolution algorithms for chaotic signals were developed.

The research also explored the development of discrete-time signal models based on iterated nonlinear maps. A powerful framework for synthesizing and analyzing such signals was developed, and led to some potentially important results. For example, broad classes of nonlinear signal models with rational spectra were developed, with rich potential applications where linear models have traditionally been used. Optimum detection and estimation algorithms with highly efficient recursive implementations were also developed for the subclass of signals we refer to as "chaotic white noise".

In addition, the synthesis of chaotic signals for use in communications applications was also explored. In particular, classes of self-synchronizing chaotic systems were developed that have potentially promising characteristics for secure communications applications. A detailed analysis of these systems was performed. Finally, preliminary work on the use of soliton signal models and algorithms for signal processing and communications applications was performed, with encouraging results.

1.3 Algorithms for Signal Enhancement and Active Noise Cancellation

During the period of this grant we developed a number of new algorithms for signal enhancement and for active noise cancellation for both single-sensor and multiple sensor systems. One class of multiple sensor algorithms for signal enhancemnt is based on modifying the E-M algorithm for jointly estimating the desired signal, the coupling systems, and the unknown signal and noise spectral parameters. The resulting algorithms take the form of either iterative or sequential time-domain algorithms. A computationally efficient implementation was developed by exploiting the structure of the underlying equations. A very different approach to multiple sensor enhancement has also been developed. This second approach is based on separating decorrelated signals. The transfer function matrix of the processor is then designed to decorrelate the sensor inputs.

In the context of active noise cancellation, a new single sensor and a new two-sensor algorithm have been developed. In the single sensor algorithm, the noise field is modeled as a stochastic process and the parameters of the process are adaptively estimated. Based on these parameter estimates a canceling signal is generated. The algorithm was evaluated with both artificially generated noise and with recordings of aircraft noise. In common two-sensor approaches to active noise cancellation, a primary microphone is placed at the point where noise cancellation is desired and a secondary microphone placed at a location which provides a correlated measurement of the noise. In most existing ANC systems, the cancelling signal is dreived only from the output of the secondary sensor. In our work we generate the cancelling signal based on the outputs of both the secondary and primary sensors. Specifically, we construct the cancelling signal as a linear combination of the past values of the outputs of the all the sensors and use a two-input/single-output LMS algorithm to maximize the noise attenuation. This new algorithm provides a significant improvement over the conventional approaches to active noise cancellation.

2 Publications

2.1 Books & Book Chapters

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